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Ice Thickness Measurement System for the Icing Research Tunnel Calibration

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ICE THICKNESS MEASUREMENT SYSTEM FOR THE ICING RESEARCH TUNNEL CALIBRATION

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ABSTRACT

To measure icing patterns across a test section of the Icing Research Tunnel, an automated rotating bar measurement system was developed at the NASA Lewis Research Center. In comparison with the previously used manual measurement system, this system provides a number of improvements: increased accuracy and repeatability, increased number of data points, reduced tunnel operating time, and improved documentation. The automated system uses a linear variable differential transformer (LVDT) to measure ice accretion. This instrument is driven along the bar by means of an intelligent stepper motor which also controls data recording. This paper describes the rotating bar calibration measurement system.

GENERAL DESCRIPTION

The iceprobe system was developed to automate documenting the liquid-water-content uniformity in the test section. The stationary vertical bars were replaced by a set of nine 1.5-in.- (38.1-mm-) diameter rotating vertical bars that are set at specific intervals across the test section, allowing uniform ice buildup around the bar. After the bars are iced, a measuring unit is brought into the tunnel and is attached to each bar at a time (fig. 1). The measuring unit (of fig. 2), a linear variable differential transformer (LVDT), traverses the bar on a dual-shaft rail system with a ballscrew driven by a stepper motor. The traverse position is measured by a string potentiometer. An intelligent stepper motor indexer controls the traversing motion and starts and stops the data recording according to preprogrammed sequences. The operator in the tunnel uses a pushbutton control unit to select these sequences. The control unit also has a selector switch to indicate the number of the bar being measured. The facility data acquisition system records the ice accretion and the corresponding traverse position for each bar. It also provides real-time display plots and transfers the acquired data to a mainframe computer for postprocessing to create contour plots.

SYSTEM DESCRIPTION

Ice Measuring Unit

The ice measuring unit (fig. 3) consists of a small, precision dual-shaft rail system that is mounted perpendicular to the bars and the traverse rails. It provides a sliding mechanism for two arms that have a cam follower mounted on the end. The cam followers ride along the bars as the device traverses the bar. The contact between the cam rollers and the bar is maintained by a spring attached to the arms, pulling them together. An LVDT measures the change in the distance between the arms, which is equal to twice the ice accretion because the measurement includes the ice accretion of the bar diameter.

The cam followers are left in the tunnel during the stabilization and icing so that they are cold when the bars are measured; warm cam followers tend to melt the ice, which could affect the measurement. Keeping the cam followers cold apparently has no effect on the ice accreted on the bar.

Traversing Motion System

An intelligent microstepping indexer and motor were selected as the central components of the control system (fig. 2). The indexer was programmed for several sequences selected by the operator using a control unit on the back of the measuring unit. These controls include power on/off, bar select, test, jog up, jog down, and stop. The control box also has lights to indicate data recording, motion, and power on.

The stepper motor has closed-loop encoder feedback and, in combination with the indexer, provides smooth motion as the ice measuring unit traverses the bar. When the operator pushes the test button, the indexer selects one of two sequences depending on the measuring probe location: at the bottom of travel or near the top. This selection allows alternating measuring from top to bottom for one bar and then from bottom to top for the next bar to reduce the overall measuring time.

DATA ACQUISITION AND REDUCTION

A distributed data system (1) provides the means of acquiring data for the measurement system. It is configured as a remote central VAX-based computer system and a facility computer system. The VAX-based system stores the data to generate the contour plots; the facility computer provides all the run-time processing for the calibration, online graphics display, and key interfaces between the test facility and the user. This system communicates with the central computer system, which is used for data storage and postprocessing.

The cloud uniformity is assessed by the accretion of ice on nine 1.5-in.- (38.1-mm-) diameter calibration bars placed in the tunnel test section. These bars are placed 9 in. (228.6 mm) apart with 18 in. (457.2 mm) between the end bars and the tunnel walls. A drive system rotates the bars, making a more even ice formation. The accretion uniformity is affected by tunnel boundary layer effects and water spray nozzle positions. Figure 4(a) shows the amount of ice on calibration bar nine. The center calibration bar was expected to have a more even accretion, the uniformity of which is represented in the flatness of the curve. The cumulative data for bars 1 to 9 are shown in figure 4(b).

As described in Ice Measuring Unit, the diameter of the iced bars is measured by the LVDT; the vertical position for the location of the measurement is preprogrammed in the intelligent stepper system. Both the accretion and vertical displacement information are stored and transmitted to the facility and central computers through a DESnet network using the DECnet protocol.

For final data processing, the raw measurements are converted to relative liquid-water content normalized to the measurement at the center bar:

$$\frac{LWC(x,y)}{LWC_c} = \frac{D(x,y) - D_{bare}}{D_c - D_{bare}}$$

where: $LWC(x,y)$ = liquid-water content at each location
 LWC_c = liquid-water content at the center of the test section
 $D(x,y)$ = diameter of the iced bar at each location
 D_c = diameter of the center iced bar
 D_{bare} = diameter of the bare bar.

This equation was modified for the automated measurement system (2).

The central computer system uses the converted measurements to generate the contour plots. A representative contour plot map of the liquid-water-content (LWC) ratios for a cross section of the test section is presented in figure 5. Hard copies of the raw data display pages and graphic plots can be obtained from a laser printer provided at the facility. This device communicates to the facility computer through an RS-232C interface.

COMPARISON OF MANUAL AND AUTOMATED MEASURING SYSTEMS

With the manual system, measurements of ice accretion were made every 2 in. (50.8 mm) along the bar. Errors were possible because the measurements were made manually by different people reading a tape measure to access

nonuniform ice accretion on a round bar (fig. 6). Further, the tunnel was operated with only five of nine bars at a time, requiring two separate runs to obtain measurements across the whole test section. Using the iceprobe (automated) system, a relatively accurate measurement is obtainable and is recorded approximately every 0.5 in. (12.7 mm) along the bar without operator measuring errors. The manual system took approximately 2 hr to gather data for nine bars. The iceprobe system takes approximately 1 hr to obtain the data for all nine bar locations. Automation reduces the tunnel operating time and provides more opportunities to test different spray nozzle configurations. With the manual system, the data were recorded and plotted by hand; the iceprobe system provides automated data recording, calculations, plotting, and calibrations.

SYSTEM UNCERTAINTY ANALYSIS

The accuracy, or uncertainty, U is calculated from the cumulative sum of the system bias and precision errors which may effect the measurements. The methodology of the uncertainty analysis is given in reference 3. Further details on the calculation are in TM-106010 (ref. 4).

The calculation for the accuracy of the ice accretion (LVDT) measurement is based on a consideration of four components. The first that may induce error is the LVDT. In this case, an unguided LVDT was selected. By design, the manufacturer's specifications suggest infinite resolution (ref. 5). The spring which tensions as the cam followers roll over the ice form is the second component. The third component is the error caused by the cam followers at the ice form contact area. Mathematical analysis shows that the error increases as the contact area arc length increases. The fourth component is data acquisition error. Three points were calculated to magnify the effect of the contact area.

The calculation of the accuracy of the traverse measurement is based on a consideration of two components. The accuracy of the string potentiometer can minimize this contribution to error. In this case, a linear absolute string potentiometer was selected. The manufacturer's specifications suggest infinite resolution (ref. 6). The second contributor is the glide system.

The best-case analysis of the ice accretion uncertainty was calculated to be ± 0.006 in. (0.015 mm), and the traverse position (string potentiometer) was calculated to be ± 0.2263 in. (5.658 mm). Table I shows the overall system uncertainty. These uncertainties were calculated by using the Abernethy uncertainty method (ref. 3). The limiting factors for error originating from mechanical assembly and coupling dominate the error in the ice accretion. The transducer accuracy dominates the error of the traverse system.

CONCLUSION

The development and installation of an automated rotating bar measurement system have led to improvements in the operation of the Icing Research Tunnel. Use of the iceprobe system to calibrate the tunnel has made possible a 50-percent reduction in calibration run time. In the choice of a device to measure ice accretion on the rotating bars, the most critical consideration was given to operating accurately and reliably in the cold environment: the linear variable differential transformer can operate in temperatures ranging from -50 to $+70$ °C and can measure thousandths of inches (hundredths of millimeters) of change whereas the manual system used a flexible tape to measure to the nearest 0.125 in. (3.125 mm). The number of data points was increased as was the accuracy in obtaining them. The data acquisition system provides online graphics plots and gives immediate feedback as to the effect of the spray nozzle locations in the spray bars. Because contour plots can be generated within minutes of test completion, they can be used as baseline plots of the cloud uniformity. Thus, it is possible to document the characteristics of various nozzle sprays.

REFERENCES

1. Fronek, D., Setter, R., Blumenthal, P., and Smalley, R., "A Distributed Data Acquisition System for Aeronautics Test Facilities, NASA TM-88961, May 1987.
2. Ide, R.F., "Liquid Water Content and Droplet Size Calibration of the NASA Lewis Research Tunnel," NASA TM-102447, Jan. 1990.
3. Abernethy, R.B., and Thomson, T.W., Measurement Uncertainty Handbook, Instrument Society of America, Research Triangle Park, NC, 1980.
4. Gibson, T.L., and DeArmon, J.M., "Icing Research Tunnel Rotating Bar Calibration Measurement System," NASA TM-106010, May 1993.

5. "ACT1000 Displacement Transducer Specification & Calibration Sheet," RDP-Electosense, Pottstown, PA, March 1991.
6. "Linear Motion Transducer Model PSA-80A(LT) Specification Sheet," Magnetec, Simi Valley, CA, Jan. 1992.

BIOGRAPHY

Theresa Gibson received a B.S.E.E. from Howard University. She is presently enrolled at Case Western Reserve University for a M.S.E.E. Her major assignments at NASA are to perform electrical and instrumentation engineering duties as applied to the operational support of aeronautic research facilities and experiments.

TABLE I.—ICEPROBE SYSTEM UNCERTAINTY

Total uncertainty, U	Range, in.	Range, mm
$U_{\text{ice accretion}}$ where $S_7 = 0^\circ$	± 0.0006	± 0.015
$U_{\text{ice accretion}}$ where $S_7 = 1^\circ$	± 0.0306	± 0.7642
$U_{\text{ice accretion}}$ where $S_7 = 10^\circ$	± 0.3057	± 7.6425
$U_{\text{traverse position}}$	± 0.2263	± 5.658

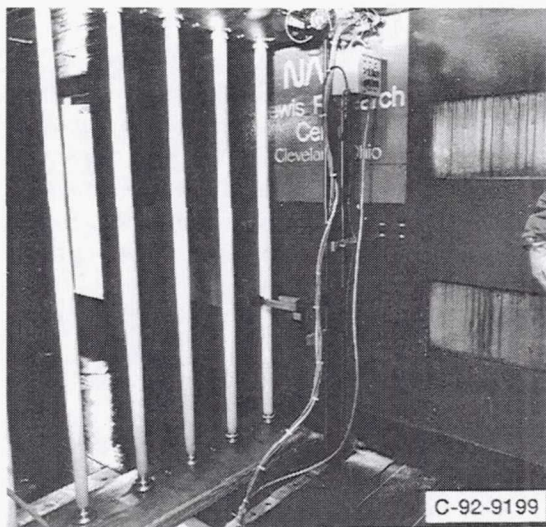


Figure 1.—Iceprobe system and control unit.

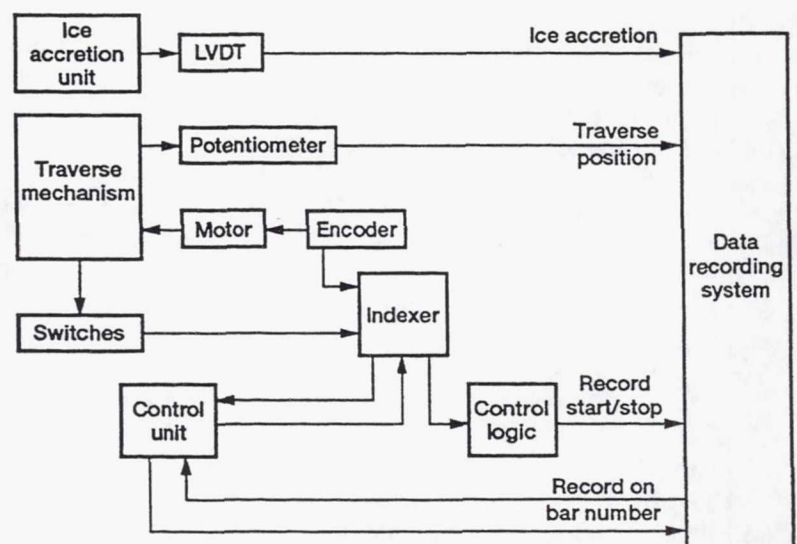


Figure 2.—Measurement and control system.

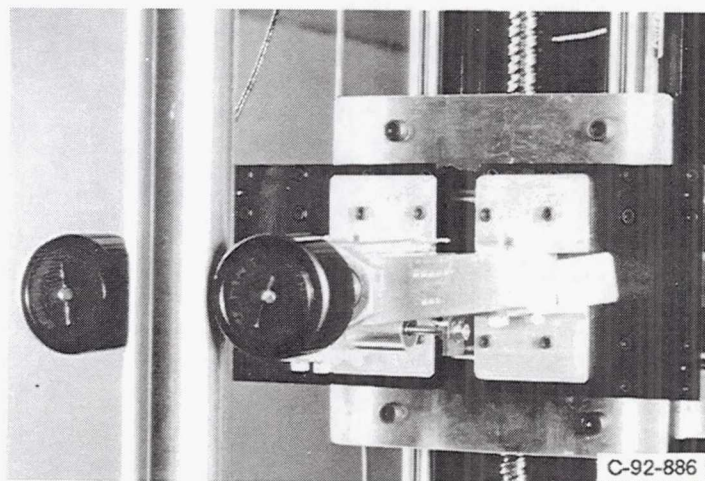
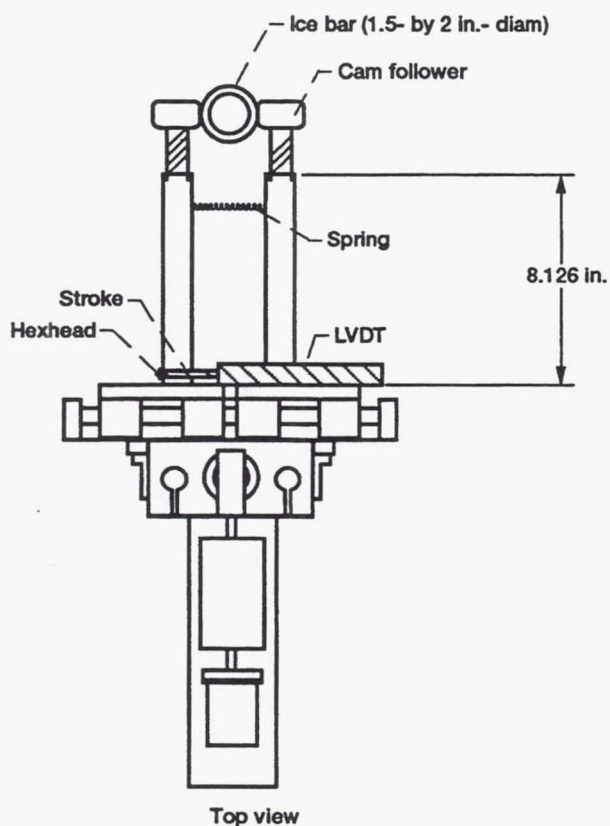


Figure 3.—Iceprobe measurement unit.

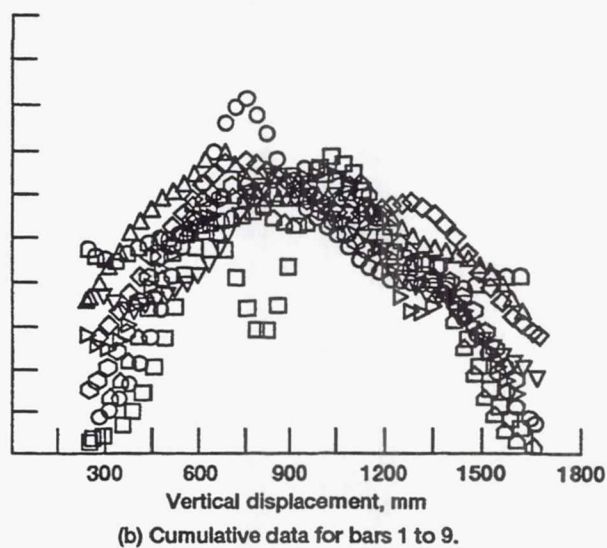
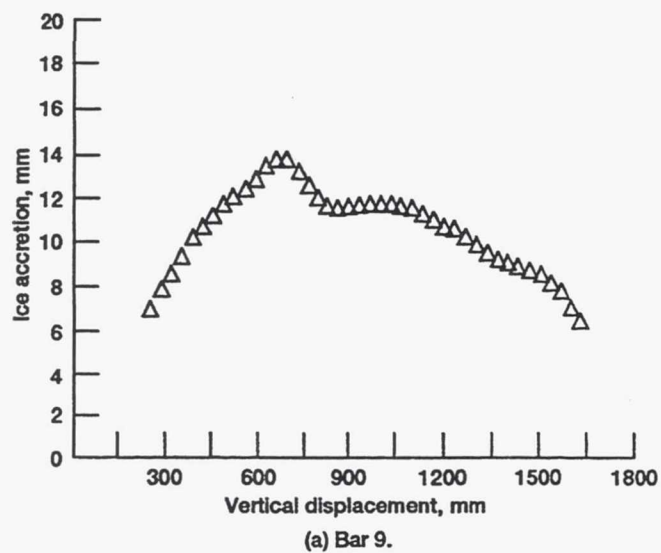


Figure 4.—Data profiles for calibration bars.

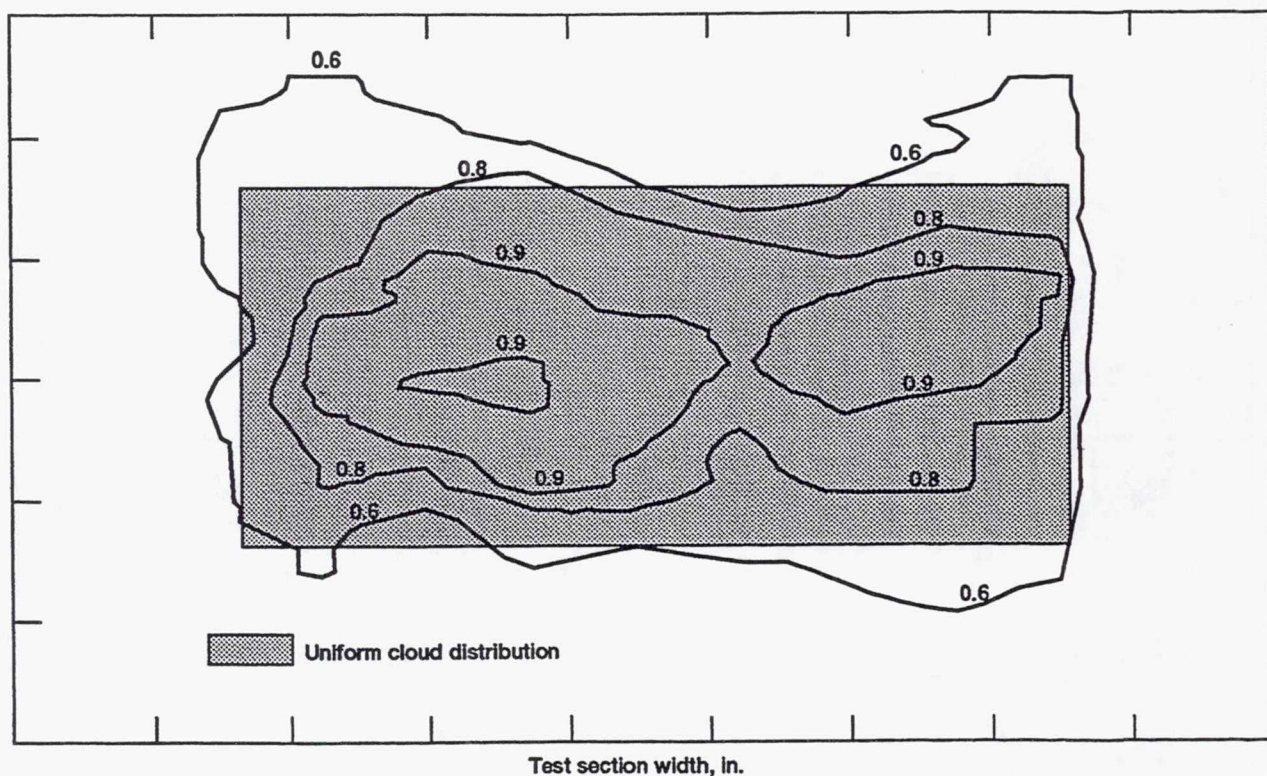


Figure 5.—Contour plot of data for bars 1 to 9. Contours are liquid water content (LWC) ratios: ratio of local diameter to bare bar diameter/center diameter to bare bar diameter.



Figure 6.—Manual ice accretion measurement.

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